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(54) A method and apparatus for separating a frozen deposit from a substrate; Aircraft de-icing.

(57) A method and apparatus for separating a deposit (1) of frozen, electrically conductive, material such as ice from a substrate surface such as the wing (8) of an aircraft (5) (Fig 4) involves the application of a layer (3) of at least one electrically conductive polymer to the surface (2) or dispersion of at least one electrically conductive polymer in the substrate of the surface (2). The deposit (1) forms on the surface of the substrate containing the polymer or on the polymer layer (3). The deposit is separated therefrom by varying the surface energy of the polymer dispersion or layer (3) between a first surface energy value at which formation of the deposit (1) occurs and a second surface energy value at which separation of at least part of the deposit (1) from the polymer layer (3) or polymer containing substrate surface (2) occurs. Copper electrodes (4) on an insulating base, e.g. alumina (4a) are provided. Substrate (2) may be metal, glass, or plastics. The polymer (3) may be polyaniline or polybithiophene or polyfluorosulphonic acid. Also applicable to vehicle window de-icing, heat exchanger de-icing, or release of frozen food items from moulds.

*Fig.1*

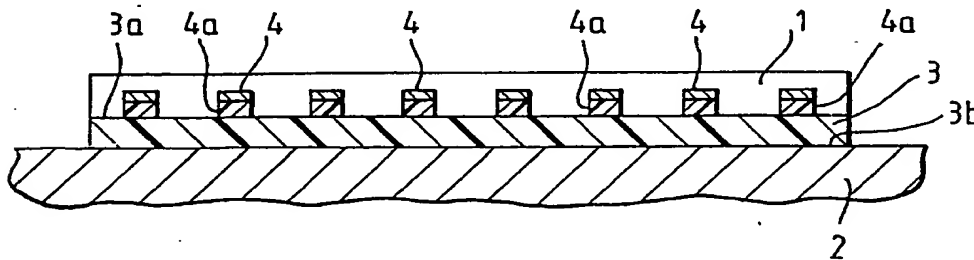


Fig.1

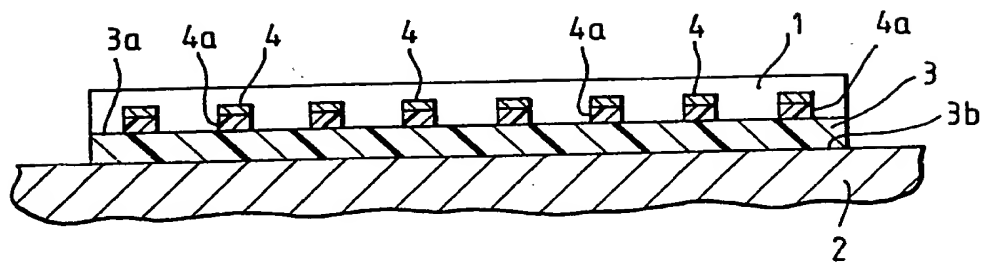


Fig.2

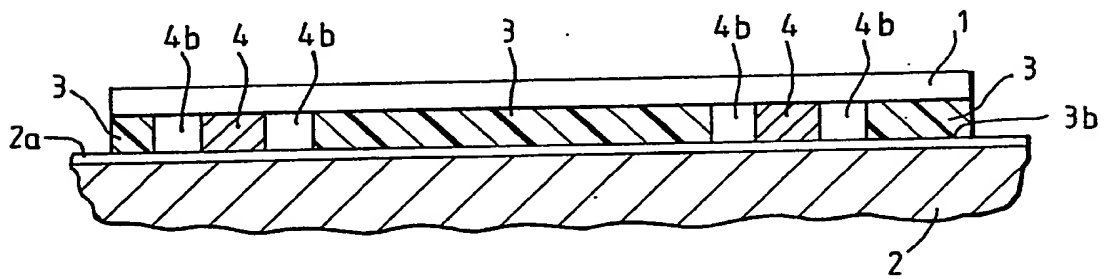


Fig.3

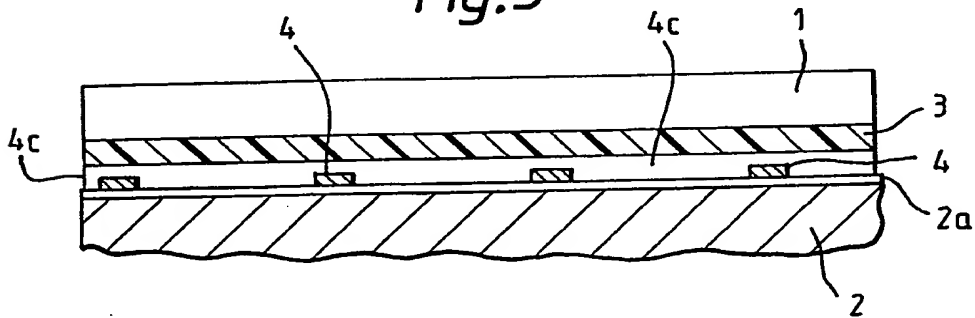


Fig.4

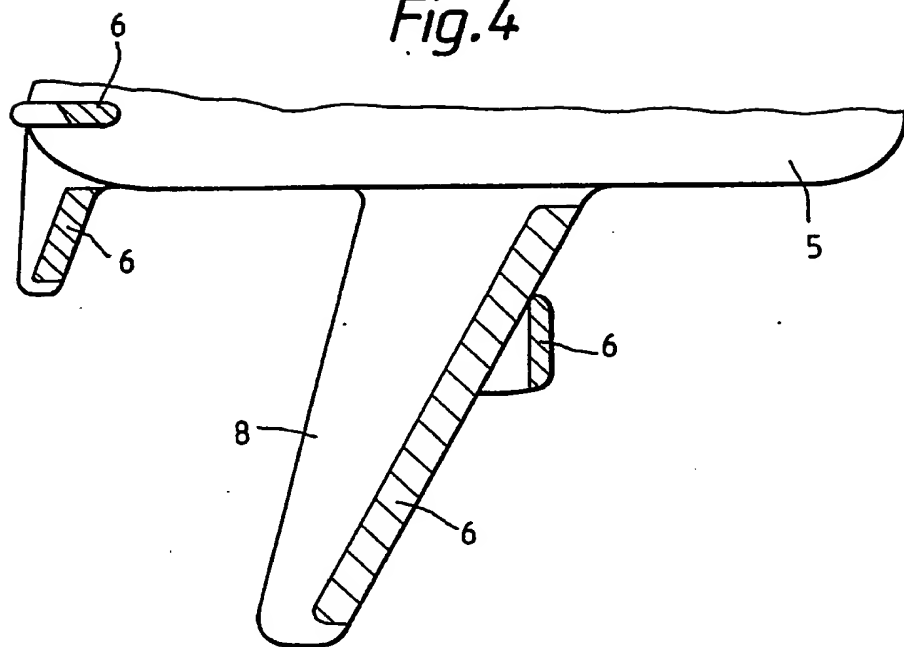
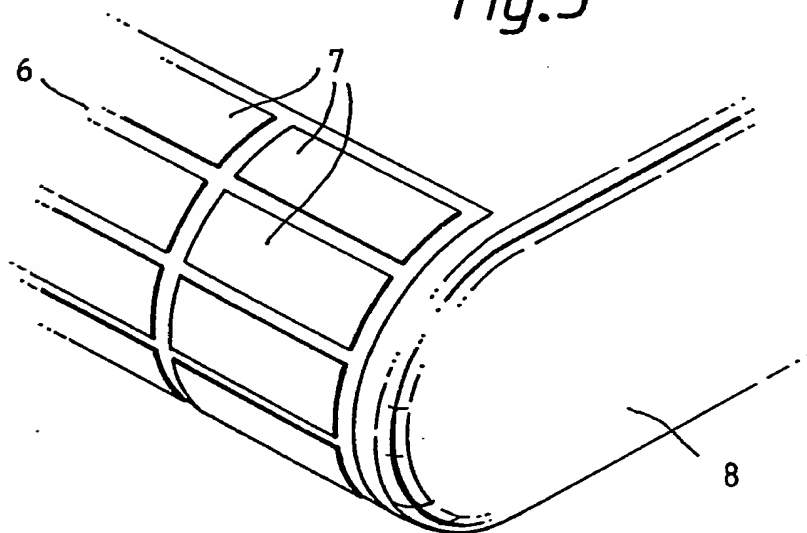


Fig.5



METHOD AND APPARATUS FOR SEPARATING A FROZEN  
DEPOSIT FROM A SUBSTRATE

This invention relates to a method and apparatus for separating a deposit of frozen, electrically conductive, material from a substrate surface and is particularly, but not exclusively, suitable for use for de-icing an aircraft.

The build up of frozen deposits such as ice on a substrate surface is particularly undesirable in many circumstances such as on land, sea air or space vehicles. The extra weight and extra drag produced by this deposit build up is particularly detrimental for ships and aircraft as it can dangerously overload the vehicle thereby impeding its handling qualities quite apart from requiring use of a greater amount of fuel. Many ways have been devised for removing or impeding the formation of such frozen deposits from aircraft or ships. These conventional methods and systems usually involve dissolving the deposit by means of spraying a de-icing fluid thereon, melting the deposit by the application of heat or breaking off the deposit by mechanical means.

In the case of aircraft a spray system requires carrying the additional weight of the system and the de-icing fluid which reduces the aircraft payload and range, heat systems place a high burden on the aircraft engines and the electromechanical systems can be variable in effect depending upon the tenacity with which the deposit adheres to the substrate surface. This

tenacity of adhesion varies with the material from which the substrate is made and is such that the system often cannot remove the layer of frozen deposit immediately in contact with and adjacent to the substrate surface but merely removes layers further away from the substrate surface. In other words the initial layer becomes, in effect, bonded to the substrate surface.

One conventional technique aimed at producing the degree of adhesion of the frozen deposit to the substrate, particularly for aircraft, has been to coat the substrate with a rubber material, a so called de-icer boot and remove any frozen deposits building up on the rubber coating material by deformation and flexing of the rubber coating. However this conventional system still requires the vehicle, such as an aircraft, to carry extra equipment to promote the deformation of the rubber coating material and this represents additional weight and cost.

There is thus a need for a generally improved method and apparatus for separating a deposit of frozen, electrically conductive material from a substrate surface which is lighter in weight, and generally simpler in operation than existing conventional methods and apparatus.

According to one aspect of the present invention there is provided a method of separating a deposit of frozen, electrically conductive, material from a substrate surface, including the steps of applying a layer of at least one electrically conductive polymer to the surface or dispersing at least one electrically conductive polymer in the substrate, so that, in operation, the deposit forms on the surface of the substrate containing the

polymer or on the polymer layer, and varying the surface energy of the polymer dispersion or layer between a first surface energy value at which formation of the deposit occurs and a second surface energy value at which separation of at least part of the deposit from the polymer layer or polymer containing substrate surface occurs.

Preferably the surface energy is switchably varied between the first and second values.

Conveniently the surface energy is varied by passing an electric current to and through the polymer dispersion or layer.

Advantageously the electric current is supplied to at least one electrical conductor located on, in, under or close to the polymer layer or polymer containing substrate such that, in operation, a deposit of frozen, electrically conductive, material on the layer or substrate contacts both the conductor and the layer or substrate to form an electrolyte therebetween to facilitate the passage of the electric current.

Preferably the electric current is supplied to at least one electrical conductor located in the polymer layer and separated therefrom by electrolyte.

Conveniently the electrolyte is a polymer membrane, preferably made of polyfluorosulphonic acid.

Advantageously the electric current is supplied to at least one electrical conductor located between the substrate and the polymer layer, and from the conductor to the polymer layer via an electrolyte membrane located between the substrate and polymer layer.

The electrolyte membrane may be made of polyfluorosulphonic acid.

Preferably the frozen, electrically conductive, material deposit is ice, the polymer is polyaniline or polybithiothene and/or the substrate is one or more of metal, glass and plastics.

Conveniently the electric current is supplied to the at least one conductor to a value such as to drive the polymer dispersion or layer to a cathodic voltage at which hydrogen evolution occurs from the deposit in bubbles which assist separation of the deposit from the substrate surface.

According to a second aspect of the present invention there is provided apparatus for separating a deposit of frozen, electrically conductive, material from a substrate surface, including at least one electrically conductive polymer for dispersion in the substrate or for forming a layer thereon, such that, in operation, the deposit forms on the polymer containing substrate or on the polymer layer, and means for varying the surface energy of the polymer dispersion or layer between a first surface energy value at which formation of the deposit occurs and a second surface energy value at which separation of at least part of the deposit from the polymer layer or polymer containing substrate surface occurs.

Preferably the means for varying the surface energy includes means for passing an electric current to and through the polymer dispersion or layer.

Conveniently the means for passing an electric current to and through the polymer dispersion or layer includes at least

one electrical conductor connectable to a source of electrical current and located on, in, under or close to the polymer layer or polymer containing substrate, so that, in operation, a deposit of frozen, electrically conductive, material on the layer or substrate contacts both the conductor and layer or substrate to form an electrolyte therebetween to facilitate the passage of electric current.

Preferably the at least one electrical conductor is mounted on the polymer layer via electrical insulation material, which electrical insulation material may be alumina.

Conveniently the means for passing an electric current to and through the polymer layer includes at least one electrical conductor located in the polymer layer and separated therefrom by electrolyte.

Advantageously the electrolyte is a polymer membrane, preferably made of polyfluorosulphonic acid.

Preferably the means for passing an electric current to and through the polymer layer includes at least one electrical conductor located between the substrate and the polymer layer, and an electrolyte membrane located between the substrate and polymer layer.

Conveniently the electrolyte membrane is made of polyfluorosulphonic acid.

Advantageously the polymer is polyaniline or polybithiothene and the substrate is one or more of metal, glass and plastics.



According to a further aspect of the present invention there is provided an air, land, sea or space vehicle having apparatus as hereinbefore defined, in the form of at least one panel formed by a layer of at least one electrically conductive polymer in contact with the substrate forming the vehicle skin and a grid of spaced apart electrical conductors overlying and in contact with the surface of the layer remote from the layer surface in contact with the substrate.

Conveniently individual conductors are operable selectively and individually to cause selective separation of the deposit along a desired path or paths.

Conveniently the vehicle has a plurality of said panels each individually selectively switchable.

For a better understanding of the present invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which;

Figure 1 is a diagrammatic cross sectional view through apparatus according to one embodiment of the present invention shown attached to a substrate and having a deposit of frozen, electrically conductive, material thereon,

Figure 2 is a diagrammatic cross-sectional view, similar to that of Figure 1, through apparatus according to a further embodiment of the present invention.

Figure 3 is a diagrammatic cross-sectional view, similar to those of Figures 1 and 2, through apparatus according to another embodiment of the present invention,

Figure 4 is a diagrammatic plan view of half of an aircraft showing areas thereon most susceptible to ice deposit build up, which areas could carry apparatus according to the present invention, and

Figure 5 is a detailed view to a larger scale and in perspective of a leading edge of a wing of the aircraft of Figure 4 showing the mounting thereon of apparatus according to yet another further embodiment of the present invention.

The method and apparatus of the present invention for separating a deposit of frozen, electrically conductive, material, from a substrate surface, is suitable for use in many different ways such as for air, land, sea or space vehicles. It is particularly suitable for de-icing such vehicles or ground based structures and for removing such deposits from heat exchangers and freezer apparatus. Alternatively the apparatus and method of the invention could be used to promote the release of a mould from a frozen food item such as ice cream or other ice containing food substances. However, for the sake of convenience the method and apparatus of the invention will be described hereinafter in terms of use for de-icing an aircraft although it is to be understood that the invention is not limited to deposits of ice and is not limited to use with aircraft.

Basically the method of the invention for separating a deposit 1 of frozen electrically conductive material such as ice from a substrate surface 2 includes the application of a layer 3 of at least one electrically conductive polymer, such as polyaniline or polybithiophene (2,2' - bithenyl - 5, 5' dyl) to the

surface of the substrate 2 or dispersing at least one electrically conductive polymer 3 in the substrate 2. The substrate may take any convenient form such as one or more of metal, glass and plastics, and a layer of an insulating material, such as a metal oxide, may extend between the polymer layer 3 and the substrate 2.

In general the skin of an aircraft is made of aluminium or an aluminium alloy anodised or painted for corrosion protection. The anodisation can result in the surface of the substrate 2 being provided by a porous open cell-like structure or layer 2a as shown in Figures 2 and 3, which can be used as a key for paints and adhesives. Such an anodised surface layer 2a forms a good key for the deposition thereon of the electrically conductive polymer layer 3.

Alternatively the aircraft skin could be a composite structure having a polymer matrix and the at least one electrically conductive polymer can be dispersed in this matrix.

In the method and apparatus of the present invention the frozen deposit 1 thus forms on the surface of the substrate 2 containing the polymer or on the polymer layer 3. The polymer is so chosen that its surface energy can be varied, whether the polymer is in the form of a dispersion in the substrate 2 or as a layer 3 on the substrate 2. The surface energy of the polymer is varied between a first surface energy value at which formation of the deposit 1 occurs and a second surface energy value at which separation of at least part of the deposit 1 from the polymer layer 3 or polymer containing substrate 2 surface

occurs. The surface energy preferably is switchably variable between the first and second values to promote consistent and repeated removal or separation of the deposit.

The surface energy may be varied by passing an electric current to and through the polymer dispersion or layer 3. Thus, when used for de-icing, the method and apparatus of the present invention employ the use of a variable surface energy polymer layer or dispersion which has the ice-phobic nature of its surface readily switchable between the first and second values by the application of an electrical field. The layer 3 may be applied to the substrate 2 in any convenient manner such as by electro deposition, chemical deposition or the like.

Electric current is supplied to and through the polymer dispersion or layer 3 from a source of electrical energy (not shown) by being supplied to at least one electrical conductor 4 made of any convenient materials such as copper, located on, in, under or close to the polymer layer 3 or polymer containing substrate 2 such that, in operation, a deposit 1 of frozen, electrically conductive material, such as ice, on the layer 3 or substrate 2 contacts, in the embodiments of Figures 1 and 2, both the conductor 4 and the layer 3 or substrate 2 to form an electrolyte therebetween to facilitate the passage of the electric current. Thus the state of charge of the polymer is altered between the first and second values by passing an electrical current to change the hydrophobicity and strength of bond between the ice deposit 1 and the polymer of the layer 3 or substrate 2. Regions of frozen deposit 1 such as ice will urge

the conductor 4 into contact with the conducting ice-phobic polymer of the layer 3 or substrate 2 and will form the electrolyte for the passage of current. De-icing or deposit separation is achieved by switching the ice-phobic nature of the polymer of the layer 3 or substrate 2 between the first and second surface energy values. This can be done repeatedly.

One suitable form of apparatus according to the present invention is shown in Figure 1 of the accompanying drawings. This embodiment is particularly suitable for use with an aircraft 5 such as in Figure 3 where areas of the aircraft 5 most susceptible to the formation of a frozen deposit such as ice are indicated generally at 6. The apparatus of the present invention can therefore be concentrated in the area 6 where icing mainly occurs so as to reduce the power requirements. In the apparatus of Figure 1 a plurality of electrical conductors 4 are employed arranged in a spaced apart grid form overlying and spaced by electrical insulation 4a from the surface 3a of the layer 3 remote from the surface 3b of the layer 3 in contact with the substrate 2. The insulation 4a may be provided by any suitable insulating material such as alumina. The conductors 4 make electrical connection with the deposit or ice 1. A polarizing voltage may then be applied to the layer 3 via the ice 1 and conductors 4.

In the embodiment of Figure 2 the conductors 4 are located in the polymer layer 3 and separated therefrom by electrolyte 4b conveniently in the form of polymer membranes made, for

example, from polyfluorosulphonic acid (NAFION - Trade Mark Dupont Industries).

In the alternative construction of the embodiment of Figure 3 the conductors 4 are located under the polymer layer 3 between the layer 3 and the substrate 2 or substrate insulating layer 2a. The electrodes 4 are in contact with the substrate 2 or layer 2a and spaced from the polymer layer 3 to which they are connected via a layer 4c of electrolyte conveniently in the form of a polymer membrane made, for example, from polyfluorosulphonic acid (NAFION - Trade Mark Dupont Industries).

The apparatus of Figures 1, 2 or 3 may take the form of at least one panel 7 as shown in Figure 5 attached to a leading edge area 6 of the wing 8 of the aircraft of Figure 4. An array of such panels 7 is thus formed along the leading edge of the wing 8. Wing loading may be used together with the panels 7 to peel the ice off the leading edge of the wing 8 by switching individual panels 7 in a particular sequence between the first and second surface energy values and/or at a particular frequency. The apparatus and method of the invention may be used alone or in conjunction with conventional techniques such as electro-impulse de-icing systems for straining the surface of the protected substrate such as a wing surface of an aircraft, by switching individual panels 7 in a particular desired sequence chosen to steer the fracture of the frozen deposit or ice layer 1 in a desired direction.

The current supplied to the conductors 4 of the apparatus of the invention may be A.C. or D.C. If the apparatus and method of the present application is used in conjunction with a conventional flexible layer on an aircraft skin such as the so called boot system, any resonance or overtones induced in the protected substrate surfaces by the boot system may be detected and used to control the frequency of an alternating current supplied to the conductors 4 and driving the change in surface energy values of the polymer layer 3 or polymer dispersions in the substrate 2. Although the panels 7 have been shown in Figure 5 in a regular linear array along the leading edge of the wing 8 they could be arranged in any desired pattern or formation to enhance or promote the detachment of a frozen deposit from a substrate in any particular desired manner. Additionally when the polymer forms a dispersion in the substrate 2 the substrate 2 may be a composite wing skin for the wing 8 or may form a patterned surface on the skin such as riblets.

Additional frozen deposit separation or de-icing effects may be achieved by driving the polymer layer 3 or polymer dispersion in the substrate 2 to a sufficiently cathodic voltage that hydrogen evolution occurs from the deposit or ice electrolyte and high pressure gas bubbles are generated which have the effect of breaking up the frozen deposit or ice. Although not shown, the conductors 4 could be incorporated in the polymer layer 3 or in a substrate 2 containing a dispersion of the electrically conductive polymer. Although in the

foregoing the melting frozen deposit or ice 1 has been considered to provide an electrolyte or part of an electrolyte for the conductors 4 it is to be understood that such electrolyte could be provided, in all or in part, by a spray of de-icing fluid. The electrolyte 4b, 4c conducts ions whilst the polymer conducts electrons and ions. The conductive nature of the polymer enables its surface energy value to be changed whilst the electrolyte permits the ions formed to pass between the conductors 4 to make the surface energy value of the polymer repeatedly changeable, that is switchable.

The apparatus and method of the present application could alternatively be employed as a coating on a window or glass or plastics such as on a car or other vehicle window for de-icing purposes.



CLAIMS

1. A method of separating a deposit of frozen, electrically conductive, material from a substrate surface, including the steps of applying a layer of at least one electrically conductive polymer to the surface or dispersing at least one electrically conductive polymer in the substrate so that, in operation, the deposit forms on the surface of the substrate containing the polymer or on the polymer layer, and varying the surface energy of the polymer dispersion or layer between a first surface energy value at which formation of the deposit occurs and a second surface energy value at which separation of at least part of the deposit from the polymer layer or polymer containing substrate surface occurs.
2. A method according to claim 1, in which the surface energy is switchably varied between the first and second values.
3. A method according to claim 1 or claim 2, in which the surface energy is varied by passing an electric current to and through the polymer dispersion or layer.
4. A method according to claim 3, in which the electric current is supplied to at least one electrical conductor located on, or close to the polymer layer or polymer containing substrate such that, in operation, a deposit of frozen electrically conductive material on the layer or substrate contacts both the conductor and the layer or substrate to form an electrolyte therebetween to facilitate the passage of the electric current.

5. A method according to claim 3, in which the electric current is supplied to at least one electrical conductor located in the polymer layer and separated therefrom by electrolyte.
6. A method according to claim 5, in which the electrolyte is a polymer membrane.
7. A method according to claim 6, in which the polymer membrane is made of polyfluorosulphonic acid.
8. A method according to claim 3, in which the electric current is supplied to at least one electrical conductor located between the substrate and the polymer layer, and from the conductor to the polymer layer via an electrolyte membrane located between the substrate and polymer layer.
9. A method according to claim 8, in which the electrolyte membrane is made of polyfluorosulphonic acid.
10. A method according to any one of claims 1 to 9, in which the frozen, electrically conductive, material deposit is ice.
11. A method according to any one of claims 1 to 10, in which the polymer is polyaniline or polybithiophene.
12. A method according to any one of claims 1 to 11, in which the substrate is one or more of metal, glass and plastics.
13. A method according to claim 12 when dependent from claim 11, claim 10, claim 8, claim 5 or claim 4, in which the electric current is supplied to the at least one conductor to a value such as to drive the polymer dispersion or layer to a cathodic voltage at which hydrogen evolution occurs from the deposit in bubbles which assist separation of the deposit from the substrate surface.

14. A method of separating a deposit of frozen, electrically conductive, material from a substrate surface, substantially as hereinbefore described with reference to Figure 1, Figure 2 or Figure 3 as modified or not by Figure 4 or Figure 5 of the accompanying drawings.

15. Apparatus for separating a deposit of frozen, electrically conductive, material from a substrate surface, including at least one electrically conductive polymer for dispersion in the substrate or for forming a layer thereon such that, in operation, the deposit forms on the polymer containing substrate or on the polymer layer, and means for varying the surface energy of the polymer dispersion or layer between a first surface energy value at which formation of the deposit occurs and a second surface energy value at which separation of at least part of the deposit from the polymer layer or polymer containing substrate surface occurs.

16. Apparatus according to claim 15, wherein the means for varying the surface energy includes means for passing an electric current to and through the polymer dispersion or layer.

17. Apparatus according to claim 16, wherein the means for passing an electric current to and through the polymer dispersion or layer includes at least one electrical conductor connectable to a source of electrical current and located on, or close to the polymer layer or polymer containing substrate, so that, in operation, a deposit of frozen, electrically conductive, material on the layer or substrate contacts both the conductor

and layer or substrate to form an electrolyte therebetween to facilitate the passage of electric current.

18. Apparatus according to claim 17, wherein the at least one electrical conductor is mounted on the polymer layer via electrical insulation material.

19. Apparatus according to claim 18, wherein the electrical insulation material is alumina.

20. Apparatus according to claim 16, wherein the means for passing an electric current to and through the polymer layer includes at least one electrical conductor located in the polymer layer and separated therefrom by electrolyte.

21. Apparatus according to claim 20, wherein the electrolyte is a polymer membrane.

22. Apparatus according to claim 21, wherein the polymer membrane is made of polyfluorosulphonic acid.

23. Apparatus according to claim 16, wherein the means for passing an electric current to and through the polymer layer includes at least one electrical conductor located between the substrate and the polymer layer and an electrolyte membrane located between the substrate and polymer layer.

24. Apparatus according to claim 23, wherein the electrolyte membrane is made of polyfluorosulphonic acid.

25. Apparatus according to claim 14, 16, 17, 20 or 23, wherein the polymer is polyaniline or polybithiothene and the substrate is one or more of metal, glass and plastics.

26. Apparatus for separating a deposit of frozen, electrically conductive, material from a substrate surface, substantially as hereinbefore described with reference to Figures 1, 2 or 3 as modified or not by Figure 4 or Figure 5 of the accompanying drawings.

27. An air, land, sea or space vehicle having apparatus according to claim 17, in the form of at least one panel formed by a layer of at least one electrically conductive polymer in contact with the substrate forming the vehicle skin and a grid of spaced apart electrical conductors overlying and in contact with the surface of the layer remote from the layer surface in contact with the substrate.

28. A vehicle according to claim 27, in which individual conductors are operable selectively and individually to cause selective separation of the deposit along a desired path or paths.

29. A vehicle according to claim 27 or claim 28, having a plurality of said panels each individually selectively switchable.

**Patents Act 1977**  
**Examiner's report to the Comptroller under**  
**Section 17 (The Search Report)**

Application number 9101855.6

**Relevant Technical fields**

(i) UK Cl (Edition K )

B7W - W46A  
HSH - H120

(ii) Int Cl (Edition 5 )

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3/22, 3/26, 3/28, 3/30, 3/34,  
3/36, 3/84

**Databases (see over)**

(i) UK Patent Office

(ii)

**Search Examiner**

B F Baxter

**Date of Search**

12 April 1991

**Documents considered relevant following a search in respect of claims**

1-29

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2080834 A RAYCHEM whole document	1, 15
A	GB 2141610 A RAYCHEM whole document	1, 15
A	GB 2196215 A JONG-TSUEN LIN whole document	1, 15
A	US 4445026 A WALKER whole document	1, 15



Category	Identity of document and relevant passages	Relevant to claim(s)

#### Categories of documents

**X:** Document indicating lack of novelty or of inventive step.

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